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ORTHOGENESIS

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ORTHOGENESIS FROM THE STANDPOINT OF THE BIOCHEMIST

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IT does not seem likely that physical science should have much to say about the theory of orthogenesis. In the first place, it is hard to see what the term means if one adopts a physico-chemical standpoint. In the second place, organic evolution is more remarkable in its morphological aspects than in its chemical and physico-chemical aspects.

I

The first point may be dismissed with a few remarks. Orthogenesis presumably means that evolution has taken place in a straight line or in a very restricted path, and that the straightness of the line depends, at least partly, upon something which is internal to the organism, though, of course, the process may be released by a stimulus from the environment. The straightness of the process must be largely a matter of definition. Physico-chemically, it could hardly mean more than that quantitative changes have steadily the same sign over a considerable period of time.

One might, perhaps, adopt such a view, if one could believe, as has been often suggested, that variation is the expression of a process which is approaching a condition

of equilibrium, because then, so far as there is no untoward interference from without, it would be natural to think that the course of the process must be in a certain sense a straight one, with a negative acceleration. Taken literally, such a consideration is, however, purely speculative and for the present, I think, a sterile speculation.

Somewhat more clearly intelligible is a hypothesis which arises from the study of hormones and their rôle in development. It appears to be quite possible that the effect of increase or decrease in the amount of a single chemical substance in a species might be a complex change in its structure, including modifications of size, of the proportions of the different parts, of pigmentation, or of the other peculiarities which ordinarily arrest the attention of students of evolution. This would be especially true if, instead of a change in the amount of a hormone or other substance, it were a case of the formation of a new compound. Such changes, while directly due to a single substance, might be greatly modified by readjustments following the disturbances of the physiological equilibria between the different parts of the body. Compensatory readjustments of similar nature are, of course, among the most familiar and interesting phenomena in pathology. We are, accordingly, fully justified in taking their possibility for granted.

It is, therefore, conceivable that evolutionary changes should be occasionally progressive and apparently orthogenetic, although due to a simple physico-chemical modification. No doubt, if it were desirable, such considerations might be developed into a clear and possibly useful theory of orthogenesis, but I am not qualified to do so. My object is only to insist that changes which from a morphological standpoint are complex, continuous, and progressive, may conceivably be due to a single, simple, physico-chemical change.

Such reflections, vague though they may be, clearly point to a conclusion which is, I feel sure, inevitable for the physical scientist; morphological phenomena in them-

selves are not sufficient to establish the validity of any theory of the mechanism of evolutionary variation.

II

More important than speculating about such questions is the fact that the underlying physico-chemical processes in living organisms seem to have remained about the same throughout the whole process of evolution. So far as it is possible to form any opinion on the matter, this conclusion is inevitable.

In considering the question of organic evolution it should always be remembered that, with very trivial exceptions, the economy of life on the earth is now and probably always has been founded upon the synthesis of carbohydrates from water and carbonic acid with the accompanying fixation of energy, followed by the conversion of carbohydrates into fats, proteins, and a great variety of other related substances. Later there is an oxidation of these substances back to water and carbon dioxide, accompanied by the utilization of the energy in various forms of organic activity. Correlated with this is the fact that cells are made up of water, carbonic acid, carbohydrates, fats, proteins, and certain other substances. They are enough alike in chemical composition and in physico-chemical structure fully to justify the concept of protoplasm as a fairly constant physico-chemical apparatus throughout the organic world.

These familiar facts of chemical physiology and chemical morphology undoubtedly depend upon the properties of the substances involved. Water and carbonic acid, with which the process begins and ends, and which seem to be everywhere the foundation of protoplasm, possess in themselves such a large number of remarkable characteristics and lead directly through the formation of sugars to such a great variety of chemical substances and chemical reactions, that it is hard to believe in the possibility of the existence on a large scale of any very different kinds of living organisms.

This is a subject that I have elsewhere discussed at length. Hence it will perhaps suffice briefly to recapitulate a few of the more striking facts. Because of its peculiarities as a solvent, as an ionizing medium, etc., water makes possible the formation of an almost indefinitely greater variety of physico-chemical systems than does any other substance. On account of its high latent heat of vaporization, its high specific heat, its high surface tension, and the peculiarities of carbonic acid, such systems often possess a very remarkable stability. The elements hydrogen, carbon, and oxygen, of which water and carbon dioxide are composed, seem to be unique in the number and variety of the substances which they can form. In particular, the production of sugar from water and carbon dioxide fixes a very great amount of energy and leads directly to the greatest variety of chemical substances and reactions which are known to occur as the result of one chemical process. Finally, water and carbon dioxide are the two substances which are everywhere available.

Anything so complex, so stable and yet so variable, so widespread and so active as life can only occur when a great variety of conditions are fulfilled. In other words, the physico-chemical systems of the organism, in order that life shall be capable of its evolution, must possess altogether exceptional characteristics, which appear to be quite impossible unless water and carbonic acid, and compounds of the three elements, hydrogen, carbon, and oxygen, and no doubt also of nitrogen, are at the basis of them. These substances possess a set of properties each one of which by itself and also in cooperation with the others is necessary for the highest physico-chemical complexity and variability. So far as we know, no other elements or compounds possess another set of properties which permit similar physico-chemical complexity or variability.

It is, I believe, for this reason that life has always operated on the same basis.

Thus while the evolutionary process has certainly produced a large number of well-defined series of changes when it is looked at from the morphological point of view, it still remains very probable that such physico-chemical changes as have occurred are not only of a secondary nature, but that they are much less of the character of serial modifications. Indeed, one is tempted to say that in a physico-chemical sense, the variations are distributed in rather a random manner, without any particular indication of a general progressive tendency, such as we seem obliged to think of in studying morphological variation.

No doubt the evolutionary process has, from time to time, invented new chemical substances and greatly modified colloidal systems. In the total these changes are very numerous and of the utmost importance to the student of evolution. But *progressive* change is more particularly a morphological phenomenon and it seems to be almost self-evident that progressive morphological evolution should not be accompanied by the same degree of continuous variation in straight lines in physico-chemical properties. Such a parallelism would, I think, be well nigh unaccountable. However that may be, there is no evidence for it.

III

Another consideration which makes the theory of orthogenesis seem very different to a physical chemist from what it must seem to a biologist, is the fact that chemistry tends to deal with individual substances which either exist or do not exist. The case of hemoglobin will illustrate this point. Hemoglobin is an individual substance of very marked peculiarities. So far as known there are no essential differences between the hemoglobins contained in the bloods of different species. It is possible that the known differences in crystal form depend upon something more than trivial differences in the amino acids which make up the molecule, but this seems unlikely. In any case, it will do no harm to speak of hemoglobin as

a single chemical individual in order to illustrate a particular point.

This substance is the sole means of transporting more than a small amount of dissolved oxygen in the blood of those species which contain it. It is, therefore, apparent that it may be thought about from the evolutionary point of view, much as one thinks about an organ. I believe that the success of Aristotle's system of classification justifies this view. But while it is easy to think of the gradual evolution of an organ as something which can not be regarded as appearing at any point in the evolutionary process, being related by a process of continuous differentiation to something which was certainly not the same organ in an ancestral species, there is not the slightest evidence for anything of the sort in the case of hemoglobin, and it must seem to most chemists nothing less than fantastic to assume such a continuous evolution of a substance more and more closely approaching hemoglobin. Moreover, it is almost as difficult to imagine such a thing from the standpoint of a biologist, and it is certainly true that any given organism either does or does not contain a substance which is capable of forming a loose chemical combination with oxygen.

But the difficulty in the case of hemoglobin is more serious than this, for it has been found that hemoglobin, like other organs, has more than one function. It has, in fact, at least three; for it is the sole means of transporting oxygen, almost the sole means of liberating carbonic acid in the lung and absorbing it in the tissues, and the instrument of the final delicate adjustment of the alkalinity of the blood. The last two functions depend upon the same property in the hemoglobin molecule, but this property is a different one from that which enables hemoglobin to combine with oxygen. We are, therefore, here confronted with the task of imagining the origin of a chemical substance, quite different in its nature from any other known substance, which possesses two chemical peculiarities, and which, as a result of these two peculiarities, performs three highly important functions.

Now it may be that originally hemoglobin possessed only one of these peculiarities, so that its sole original function was to carry oxygen. And accordingly one of the most interesting questions of comparative physiological chemistry concerns the respiratory function of the blood. It would be a very important discovery to find a kind of hemoglobin in which there is no specialized action upon the transport of carbonic acid and upon the alkalinity of the blood. But even if the earliest hemoglobin were of such a nature, the first production of hemoglobin would still seem to have been relatively an extremely discontinuous variation involving an unmistakable physiological unit of great importance.

It is true, and should be noted in order to avoid confusion, that there has been a later evolution of the process of oxygen transport. This has been commented on by Barcroft as a result of his own important researches. It appears that variation in the electrolytes of the red cells is accompanied by remarkable variation in the affinity of their hemoglobin for oxygen, and that this is the explanation of the differences in the so-called oxygen dissociation curves of the bloods of different species of mammals. Here, as Barcroft points out, there is no difficulty in imagining a process of adaptation, for the fact of chemical discontinuity is not involved. It is a question of changing proportions of the different substances.

But in spite of the possibility of such phenomena, it seems probable that there are, even in the human species alone, a considerable number of important individual substances whose appearance in the course of organic evolution it is very difficult to imagine, except as a radical innovation.

Accordingly, it must be apparent that in the present state of our knowledge, any theory which postulates continuity in evolution is very unsatisfactory to the chemist.

Moreover, in this case one seems to be confronted with an appearnace of discontinuity which does not depend, as is too often the case, upon a judgment of the magnitude of a difference.

Of course, it is not difficult to imagine a sufficiently close approach to continuity of evolution, and therefore, to orthogenesis, in the case of simple proteins. But here, very likely on account of our ignorance, there is no indication of anything more than indefinite variation and variability, accompanying variation in a definite direction in the morphological characteristics of species.

On the whole, variation in the ultimate physico-chemical nature of organisms seems to have been rather discrete than continuous, not orthogenetic, but distributed at random. Such a conclusion may possibly be illusory, for our ignorance is greater than our knowledge. But whatever the nature of the changes which it has undergone, the most striking thing about the physico-chemical nature of protoplasm seems to be its uniformity throughout nature.

Therefore, with due reservations because of the incompleteness of bio-chemical knowledge, it seems reasonable to suppose that apparent instances of orthogenesis may sometimes depend upon a single important chemical change in an organism, followed by slow and progressive modifications leading up to a definitive morphological result. Such a process would be somewhat analogous to the establishment of a condition of equilibrium.